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STOVL Aircraft Simulation for Integrated Flight and Propulsion Controls Research

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STOVL AIRCRAFT SIMULATION FOR INTEGRATED FLIGHT AND PROPULSION CONTROLS RESEARCH

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ABSTRACT

The United States is in the initial stages of committing to a national program to develop a supersonic short takeoff and vertical landing (STOVL) aircraft. The goal of the propulsion community in this effort is to have the enabling propulsion technologies for this type aircraft in place to permit a low risk decision regarding the initiation of a research STOVL supersonic attack/fighter aircraft in the late mid-90's. This technology will effectively integrate, enhance, and extend the supersonic cruise, STOVL, and fighter/attack programs to enable U.S. industry to develop a revolutionary supersonic short takeoff and vertical landing fighter/attack aircraft in the post-ATF period.

A joint NASA Lewis and NASA Ames research program, with the objective of developing and validating technology for integrated-flight propulsion control design methodologies for short takeoff and vertical landing (STOVL) aircraft, has been planned and is underway. This program, the NASA Supersonic STOVL Integrated Flight-Propulsion Controls Program, is a major element of the overall NASA-Lewis Supersonic STOVL Propulsion Technology Program. It uses an integrated approach to develop an integrated program to achieve integrated flight-propulsion control technology.

Essential elements of the integrated controls research program are realtime simulations of the integrated aircraft and propulsion systems which will be used in integrated control concept development and evaluations. This paper describes pertinent parts of the research program leading up to the related realtime simulation development and remarks on the simulation structure to accommodate propulsion system hardware "drop-in" for "real" system evaluation.

INTRODUCTION

During the 1970's many innovative aircraft configurations were proposed as viable solutions to powered-lift vertical/short takeoff and landing (V/STOL) mission requirements. High performance propulsion systems were conceived for these V/STOL aircraft. The current interest in powered-lift aircraft centers on short takeoff and vertical landing (STOVL) configurations, ostensibly to compromise propulsion requirements for vertical takeoff and reduce or to eliminate the so-called "STOVL penalty".

There are currently five supersonic STOVL propulsion concepts under consideration. Four of these concepts with typical aircraft configurations are shown in Figure 1. They are: ejector augmentation, deflected or vectored thrust, remote burning augmented lift, and tandem fan. The fifth, not shown here, is the lift-plus-lift-cruise concept. The configurations shown here were generated by American aircraft manufacturers under the US-UK ASTOVL Program.

Using the same five propulsion concepts, British aircraft manufacturers designed a similar set. Under the aforementioned program the aircraft designs were used as a basis for concept evaluation to determine which technology areas required development.

The primary problem in developing propulsion system concepts for these aircraft is to design systems which provide the required aircraft handling qualities in powered-lift modes without sacrificing the powerplant of the ability to perform economically and safely within limits. During low speed operations STOVL aircraft are not only dependent upon the propulsion system for lift, but also for the forces and moments needed for flight path and attitude control. Powered-lift aircraft differ from wing-borne flight only in terminal operation modes, that is, short-takeoff, transition to hover, hover, and vertical landing. Transition is generally without complication of mission requirements or duress. However, this mode requires considerable coordination and pilot integration and thus, high workload. Thus, highly coordinated flight and propulsion control systems are critical to the success of these advanced STOVL aircraft. Although the integration of flight and propulsion controls must eventually be considered throughout the entire flight envelope of the vehicle, the primary concern remains in the subsonic flight phase and terminal operations.

Historically, aircraft design has been based on the philosophy that flight and propulsion controls can be designed independently. This philosophy assumed that the pilot could effectively integrate these subsystems by his control inputs. Future mission requirements, especially for powered-lift aircraft, will demand improved operational capabilities. Thus, the pilot's attention can no longer be shared with integrating the flight and propulsion control subsystems. The pilot must instead direct attention to higher levels of concern as demanded by the mission and monitor the progress of the mission through the imposed threats. The integration of the flight and propulsion subsystems on a control law basis will allow the pilot greater attention to those higher levels of concern by supplanting a substantial part of the pilot's integration function and thereby reduce pilot workload.

Classical design methods and approaches are generally inadequate to attack integrated control since they do not account for, in a systematic manner, the inherent cross-couplings of an integrated system. For advanced aircraft it will be necessary to treat the entire aircraft as one dynamic system. Therefore, advanced design methods within the context of an integrated control design methodology must be employed to achieve this high level of aircraft systems integration. The degree of coordination required between airframe and engine control designers will have to be increased well beyond that of conventional programs. A process to accomplish such an integrated design is shown in Figure 2. Central to the design process is the control design activity. In this element, the control design methodology determines how the interaction between propulsion and aircraft control designers is handled. The Design Methods for Integrated Control Systems (DMICS) program (Joshi et.al. [1985], Smith et.al.[1984]) conducted by the Air Force in the early mid-80's addressed this design interaction and produced methodologies which are of prime importance to integrated flight-propulsion control technology development.

Supersonic STOVL Integrated Flight-Propulsion Control Program

The goal of the propulsion community is to have the enabling propulsion technologies in place to permit a low risk decision regarding the initiation of a research STOVL supersonic attack/fighter aircraft in the late mid-90's. This technology will effectively integrate, enhance, and extend the supersonic cruise, STOVL, and fighter/attack programs to enable the U.S. industry to develop a revolutionary supersonic short takeoff/vertical landing fighter/attack aircraft in the post-ATF period. The benefits associated with STOVL include runway independence and basing flexibility for aircraft with high survivability and maneuverability.

Since the successful development of a supersonic STOVL aircraft is propulsion driven, propulsion technology issues are the key critical technologies required to achieve this goal. Within these technology issues, integrated flight-propulsion controls is considered one of the enabling technologies which will permit demonstration of the design capability to provide viable powered-lift propulsion systems.

Integrated control technology derives primarily from flight control requirements and other technology elements common to advanced STOVL aircraft. These include control force/moment generator performance, their effect on stability and control, and integrated flight-propulsion control design methodology; it is necessary to investigate the relationship between these elements and aircraft performance and aircraft handling qualities. The objectives of a program to achieve this should include: (1) the evaluation of control force and moment capability of thrust effectors which may be used in STOVL propulsion configurations, (2) the evaluation of the stability and control characteristics using aerodynamic and aero-propulsion predictions, and (3) the definition of integrated flight-propulsion control concepts. The second objective is within the realm of flight dynamics. The first and third, however, require an interdisciplinary approach with the results injected into the second objective. If integrated flight-propulsion control is a prime technology area then it follows that an integrated program approach is necessary.

On the basis of the flight control technology requirements and the strength of the V/STOL Controls Analysis and DMICS programs, a joint NASA Lewis and Ames controls program for supersonic STOVL aircraft was developed to generate the required integrated control technology and to validate its effectiveness [8,13]. The overall objective of the NASA Supersonic STOVL Integrated Flight-Propulsion Control Program is to define and develop integrated control technology for achieving supersonic STOVL flight-propulsion controls integration: (1) to enable controlled transition from takeoff to forward flight to hover with reduced pilot workload, (2) to enhance aircraft handling qualities through propulsion control, (3) to extend control logic across the total flight environment, (4) to assess unique supersonic STOVL operating requirements, and (5) to refine propulsion system and control modeling for piloted simulation.

The approach uses cooperative design, simulation, and experimental facilities of aircraft and propulsion centers to jointly develop, evaluate, and validate supersonic STOVL integrated flight-propulsion concepts. Elements of this program approach include: (1) analytical modeling of non-realtime and realtime models of supersonic aircraft (NASA-Ames) and propulsion systems (NASA-Lewis) for controls analysis and piloted simulation, (2) identification of integrated control design approaches and concepts by application of advanced and modern control methods and theories, (3) performance evaluations of control system concepts using piloted simulation on the NASA-Ames Vertical Motion Simulator (VMS) and experimental system evaluations on the NASA-Lewis Powered Lift Facility (PLF) including aircraft simulations to verify analytical results, and (4) use of planned supersonic STOVL control effector component/engine integration tests on the PLF to determine their transient effects on aircraft force and moments and to improve modeling and control concept fidelity.

Specific elements of the program are shown on Figure 3. These are grouped into: (1) Control Effector Dynamics, (2) Integrated Flight-Propulsion Control Concepts, and (3) Integrated Controls Methodology. The issues involved in the third element revolve about the approach to integrated controls technology validation of integrated control concepts while stressing the generic aspects of controls technology. In validation, advantage must be taken of existing technology programs while applying current methodologies such as DMICS in the controls discipline with the goal of extending and validating integrated control technology. Generic controls issues include system complexity and design methodology. Design methodology is of

importance to the program element. The current approach is to take advantage of concepts of opportunity by considering existing databases, status of simulations, propulsion system availability, existing experimental programs, overall system complexity, and the application to a possible flight program.

A specific STOVL concept has only a minor effect on the development of integrated controls. Since flight/propulsion controls are historically systems oriented, issues such as system complexity, multivariable and interactive character, design methodology and broadness of methodology applicability are the major items of interest. The ejector augmentor concept in the U.S.-Canada STOVL Technology Program meets these criteria.

Integrated Controls Research Demonstrator Program

The U.S.-Canada STOVL Technology Program is an on-going program between these governments to validate the technology and evaluate a viable ejector-augmented powered-lift propulsion system for a full-scale supersonic STOVL aircraft. The program is a cooperative effort between NASA and Industry Science and Technology Canada (ISTC) and involves DeHavilland, General Electric, Systems Control Technology and General Dynamics as contractors. Large-scale experimental evaluations involve, specifically, the General Dynamics E-7D aircraft design and a General Electric F110 engine with DeHavilland ejectors. The large-scale aircraft model and propulsion system will be evaluated on the PLF and the NASA-Ames National Full-Scale Aerodynamics Complex (NFAC) as well as the Outdoor Aerodynamic Research Facility (OARF). The program forms a unique research capability on which to conduct integrated controls research.

The U.S.-Canada STOVL Technology Program is depicted in Figure 4. Using aircraft model data, a simulation of the aircraft and propulsion system will be generated for use in integrated controls analysis and evaluation. The aircraft model and propulsion system hardware, including controls, will be mounted on the NASA-Lewis PLF. The aircraft and its flight dynamics along with a simulation of a human pilot will be simulated on the NASA-Lewis Controls and Simulation Laboratory which consists of two Applied Dynamics International (ADI) System 100 digital computers. The entire integrated control including the propulsion and flight control will be programmed into a real flight-type breadboard control computer. System evaluation will be accomplished by using a paper pilot to "fly" the aircraft through prescribed flight exercises. Testing at this point will also include further ejector dynamics validation and reaction control bleed effects on the engine. Subsequent to the PLF program, a final phase of evaluation will include ground effects testing of the E-7D on the OARF, large-scale aerodynamics testing on the NFAC at NASA-Ames and final integrated control evaluation for handling qualities on the NASA-Ames VMS.

Simulation Development

A complete E-7D aircraft system simulation is to be developed by combining an F110 engine model (NASA Lewis) with an E-7D aircraft model (NASA Ames); each of these models will be programmed in the ADI System 100 real-time programming language known as ADSIM. Aircraft system dynamics and flight control studies will be conducted by researchers at NASA Lewis with support from the research contractors and evaluated at the NASA Lewis Controls and Simulation Laboratory. It is anticipated that two System 100 computers will be involved in the simulation, one for the propulsion system simulation and the other for the airframe simulation; the two systems interact through ADI real-time input/output commands (ADRIO). The arrangement of the AD100 computers and communication paths is depicted in Fig.5. While this arrangement initially complicates the overall E-7D system simulation, such a configuration permits the engine software to be rapidly replaced with F110 hardware.

The E-7D/F110 hardware will be mounted on the NASA Lewis PLF. Since ADRIO will also interface the test stand with the ADSIM airframe simulation and propulsion control software, the result is a hardware "drop-in" capability that provides a rapid, low-risk, and powerful system development and validation feature.

Final evaluation will include wind tunnel testing of the full scale E-7D at NASA Ames and an integrated control evaluation for handling qualities on the NASA Ames VMS; the latter facility has recently been upgraded to include an AD100 (see reference 3) and will run the same aircraft ADSIM simulation as that used for the NASA Lewis effort.

E7-D / F110 STOVL MODEL

Overview

The proposed E-7D aircraft is based on an F-16 airframe and a F110 engine (see Jenista et.al. [1987]). STOVL capabilities derive from the installation of two ejector augmentors, a ventral nozzle, a reaction control system (RCS), and a 2D-CD cruise nozzle; these devices can be thought of as propulsion control effectors. Conventional elevons and rudders serve as aerodynamic control effectors. Approximate component locations on the E-7D are shown in Fig. 6. Manual control effector integration for this aircraft results in a difficult high pilot workload situation for three basic reasons: (1) the *number* of control effectors, (2) the coupled nature of the propulsion controls, and (3) the additional airframe/propulsion interactions. Low speed flight creates an especially complex pilot integration task since propulsion and aerodynamic control devices are used simultaneously. For these reasons it is clear the E-7D aircraft must incorporate an integrated flight/propulsion control system (IFPC).

Figure 7 illustrates the proposed relationships between the flight control system and the propulsion control system to form an IFPC system. The figure also illustrates that a complete non-linear simulation of the E-7D is an assemblage of three basic simulations: (1) the propulsion system, (2) the airframe, and (3) the control system. A hierarchical and decentralized DMICS approach is currently being applied in the IFPC control design. Here, a generalized control design philosophy permits separate treatment of mission level and functional level problems. Flying qualities and hover performance are examples of mission level design problems; function level problems involve, for instance, engine surge margin and aircraft control surface rates. Reference [16] remarks on this DMICS design procedure in more detail.

A cooperative approach to the simulation effort is reflected in the task responsibilities shown in Figure 8. Two features of the simulation in-progress are the pilot interface options and the engine hardware drop-in capability. The "paper pilot" refers to the work of Vogt et. al. [1989] which has resulted in a computer simulation of a pilot in V/STOL aircraft. Although a man-in-the-loop simulation capability is planned as an alternative to the paper pilot, it is expected the paper pilot will initially provide the necessary input to the Maneuver Command Generator (MCG). The E-7D simulation also provides selection between F110 hardware and the real-time simulation (discussed in the next section). Here, the ADSIM F110 simulation will combine the engine plant and the propulsion control simulation. Fine tuning of the control after hardware implementation is anticipated; a modular simulation approach simplifies the ensuing iterations between software and hardware. It is evident that the various propulsion module and pilot interface options require a flexible simulation structure and clearly defined module interfaces.

"Fast" and "slow" subsystems can often be identified within complex dynamic systems like the E-7D. For real-time simulations of such systems the technique of multiple frame-rate integration is appealing; the basic idea is to make an integer multiple of fast sub-system integration passes for each pass of the slow sub-system. For a tertiary frame-rate scenario the control system will be faster than the combined aircraft and engine models, and the engine model faster than the airframe model; this situation is depicted in Fig.9. An example implementation of multiple frame rate integration on the System 100 computer is discussed by Haraldsdottir and Howe [1988].

Propulsion System Model

A detailed F110 engine simulation is required for accurate propulsion system representation. A useful and practical real-time simulation approach involves tying together several basic engine components. Typical F110 components are compressors, turbines, nozzles, and ducts; Fig. 10 depicts the proposed F110 component assembly and associated system control variables. Component mathematical descriptions are obtained by applying basic conservation laws that focus on the component physics of interest. This general approach has been previously implemented on hybrid computers (see Szuch et. al.[1982] and Seldner et. al.[1972]) and more recently on digital computers (ADI[1987], Ballin[1988]).

Of specific interest in the F110 simulation are the propulsion system components unique to STOVL aircraft, particularly thrust augmenting ejectors, feeder pipes, and a ventral nozzle. Also of interest is the impact that the presence of the ejector and ventral nozzle will have on tailpipe dynamics. In the interest of brevity, this paper has chosen to remark on two features of the E-7D simulation in-progress that have the most impact on simulation speed, accuracy, and coding. The first discussion comments on the basic options for compressor and turbine component representations, and the motivation for selecting the 'backbone' approach for the first E-7D simulation. The second discussion points out that the re-introduction of volume dynamics into a digital simulation is rational in light of state-of-the-art hardware available for real-time simulation. We believe these discussions capture the basic propulsion system simulation philosophy in the present work.

Backbone Component Representations

Compressor and turbine component blocks receive input information and provide as output the performance characteristics of each component, within a pre-determined range of operating conditions. The generic fan block shown in Fig. 11a emphasizes that the non-dimensional component representation is the heart of component specification. Several techniques are known for modeling of fans, compressors, and turbines; the simulation goal is to have as accurate a component representation as possible without the need for excessive computer memory.

The traditional and simplest approach to component modeling involves direct use of component data presented, for example, in the form shown in Fig. 11b. While this approach is convenient, it does not easily allow for accurate scaling of existing data for new or advanced component performance criteria, or permit extensive manipulation of component behavior. Some concern also arises in the potential amount of computer memory the off-design component representation may consume. These concerns have lead to exploration of alternate component representation approaches.

Seldner et.al.[1972] discuss a "stage stacking" method for multi-stage components that solicits overall component behavior by blending together individual stage descriptions. This approach is attractive when interstage dynamics are of interest or when detailed flow states are needed in analysis.

Converse and Griffin[1984] present a summary of a "backbone" map fitting technique based more on the physics of the component rather than curvefits of parameters obtained by dimensionless analysis. A block diagram of the basic computational modules for this approach is summarized in Fig.11c. Although this method requires some insight on the thermodynamics of the component cycle, it is quite compact and easily scaled to new performance ranges. For the first version of the present simulation effort the "backbone" map representation will be used due to the simplicity of scaling and ease of interface with GE/F110 data received in such a format. Future efforts are planned in which component data maps are directly used and simulation results compared with the backbone method so that quantitative remarks on storage, speed, and accuracy can be made.

Volume Dynamics

Two basic perspectives can be taken in the modeling of intercomponent volume dynamics for real-time simulation of STOVL propulsion systems. For the limited purpose of generating differential equations (to link static components) the first (and simplest) approach involves control-volume heat and mass balances. The second approach includes a momentum balance and replaces the energy equation with an entropy balance -- this relatively complex development is explored if the physics of the situation warrant accurate mass, momentum, and energy storage representations.

Motivation to consider these two approaches in the present work extends from the observation that conventional FORTRAN propulsion system simulations often dispose of volume dynamic elements associated with volume dynamics. Although volume dynamics equations were an essential part of the "well-posed" mathematical problems required by hybrid (digital/analog) computer simulations, many digital computer simulations can accommodate reduced-order representations through iterative mass balancing techniques. Here, we think of the "well-posed" problem as one with as many differential equations as unknown state variables. The basic idea was that the iterations associated with mass balancing potentially consume less time than direct numerical integration of the displaced equations.

The state-of-the-art in simulation is, however, changing. Modern digital computers specifically designed for continuous simulation of dynamic systems, e.g., the ADI System 100, accommodate well-posed problems more naturally than replacement iterative schemes. The System 100 real-time simulation language, ADSIM, can efficiently re-align (optimize in-line) and execute non-procedural code more quickly if the problem is well-posed. For the case of a gas turbine simulation this mandates re-introduction of the intercomponent volume dynamics equations.

Intercomponent volumes are therefore featured in the present propulsion system for two basic reasons: (1) accurate simulation of component mass and energy storage representations are required, and (2) gas dynamics can relieve simulation iterative solution demands by providing the necessary system differential equations.

Aircraft Model

The aerodynamic model under development is based on wind tunnel data which covers a complete range of flight conditions; a model with an accurate terminal flight aerodynamics (take-off, transition, and hover) including ground effects and induced aerodynamics is of immediate concern in the present work. As a result, it has been specified in the US/Canada STOVL Controls Technology Program that the aerodynamic database is only required for a flight speed up to Mach 0.5.

In order to simplify database updates and provide modeling flexibility for the non-linear six-degree-of-freedom (6DOF) simulation, a component buildup procedure for the aerodynamic model has been employed. Although a more detailed discussion of the 6DOF equations and specifications is given by Systems Control Technology [1988], six fundamental equations are the core of the simulation; they are:

$$F_x = C_D \bar{q} S_w + \Delta F_{x, ej} + \Delta F_{x, vn} \quad (1)$$

$$F_y = C_Y \bar{q} S_w + \Delta F_{x, ej} \quad (2)$$

$$F_z = C_L \bar{q} S_w + \Delta F_{x, ej} + \Delta F_{x, vn} + \Delta F_{x, rcs} + \Delta F_{x, hover} \quad (3)$$

$$M_x = C_M \bar{q} S_w \bar{c} + \Delta M_{x, ej} + \Delta M_{x, rcs} + \Delta M_{x, hover} \quad (4)$$

$$M_y = C_M \bar{q} S_w \bar{c} + \Delta M_{y, ej} + \Delta M_{y, vn} + \Delta M_{y, 2dn} + \Delta M_{y, rcs} + \Delta M_{y, hover} \quad (5)$$

$$M_z = C_N \bar{q} S_w \bar{c} + \Delta M_{z, ej} + \Delta M_{z, vn} + \Delta M_{z, rcs} \quad (6)$$

unpowered → |----- *powered* -----→

In the ADSIM language function tables will be used for coefficient data input. The build-up approach distinguishes between components associated with powered and unpowered aerodynamics. We expand on this concept below.

Unpowered Aerodynamics

Unpowered aerodynamic coefficients describe aircraft aerodynamic behavior in the absence of powered lift jetstreams. The skill in proceeding with this problem is in quantifying the influence, for instance, that the ejector door position will have on E-7D aerodynamics. A simple simulation structure follows if component-specific excursions from a conventional aerodynamic derivative are entertained. As an example, the non-dimensional lift coefficient is given by the sum

$$C_L = [C_L(\alpha, \delta_e, \beta) + C_L(\dot{\alpha}) + C_L(q)] + \Delta C_{L_{GE}} + \Delta C_{L_{SB}} + \Delta C_{L_{EJD}} + \Delta C_{L_{2-DN}} \quad (7)$$

where the various lift coefficient changes are indicated through subscripts, and denote an account of ground effect GE, speed brake SB, ejector door position EJD, and 2-D nozzle position 2-DN. Although additive, it is not initially assumed the components of the equation are, individually, linear functions. In practice, some are non-linear functions of two variables.

Powered Aerodynamics

During powered lift flight the discharge stream emanating from, for instance, a thrust augmenting ejector, is responsible for aerodynamic flow field modifications that must be accounted for in the airframe force and moment balances. Such un-conventional jet effluxes are also responsible for hot gas injection and other ground proximity effects during take-off and landing. The E-7D 6DOF simulation provides for these STOVL realities through the force and moment increments (ΔF , ΔM) on the right-hand-side of Eqns.(1)-(6).

Induced aerodynamic increments are generally considered functions of three variables: angle-of-attack, elevon position, and effective velocity ratio, the latter defined by

$$V_e = \sqrt{\frac{2 A \bar{q}}{F}} \quad (8)$$

Here, the velocity ratio blends together Mach number and nozzle pressure (NPR) variables that would otherwise have to be treated independently.

Figure 12 is an example from Akhter et. al.[1989] of a typical induced aerodynamic effect arising from ejector operation. Other influences the complete simulation will include are those due to the ventral nozzle VN, the reaction control system RCS, the two-dimensional nozzle 2-DN, and hovering HOVER; reference [3] provides more detail on these effects.

Control System Simulation

Development of design methodologies for integrated control systems (DMICS) is an ongoing effort by many researchers in the area of IFPC design [12,16,17]. In the present work the hierarchical and decentralized DMICS design approach described by Shaw et. al.[1988] is to be applied. The general framework of the design process was described earlier and depicted in Fig.2. In Fig.13 a more detailed version of the IFPC block diagram is presented. It is emphasized that the design employs *thrust* signal feedback in the control system (as opposed to pressure signal feedback). This subtle feature adds to the innovative flavor of the present IFPC simulation activity and distinguishes it from previous simulation efforts.

Once the propulsion system and aircraft control laws have been established by SCT, ADSIM programming of the airframe control laws will be programmed by NASA Ames; NASA Lewis will be responsible for the propulsion control law programming.

At the present time the general framework and specifications for the E-7D control laws are under development.

CONCLUDING REMARKS

The overall objective of the NASA Supersonic STOVL Integrated Flight-Propulsion Control Program is to define and develop integrated control technology for achieving supersonic STOVL flight-propulsion controls integration. The real-time ADSIM simulation is an essential element of the integrated control concept development and evaluation.

The magnitude of the simulation development has dictated a cooperative program approach among the NASA centers and contractors. Site responsibilities correspond with recognized expertise at each facility. The final ADSIM code will represent a modern and flexible approach to aircraft *system* simulation and remain an important IFPC concept development and evaluation tool.

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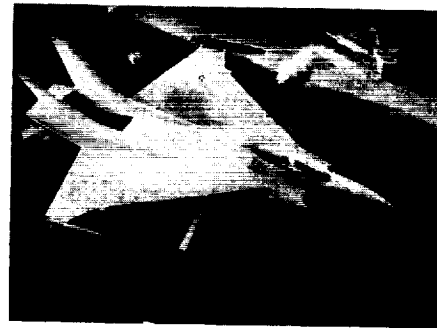
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NOMENCLATURE

A	Reference area
\bar{c}	Reference length
C_D, C_Y, C_L	Force coefficients for drag, sideforce, and lift.
C_M, C_L, C_N	Moment coefficients for pitch, roll, and yaw
F_x, F_y, F_z	Lift, drag, and side forces in body axes
M_x, M_y, M_z	Pitch, roll, and yaw moments
\bar{q}	Reference dynamic pressure
S_w	Wing planform reference area
ΔC_L	Lift coefficient increment
α	Angle of attack
$\dot{\alpha}$	Time rate-of-change of angle of attack
β	Sideslip
δ	Control surface deflection
Subscripts	
EJ	Ejector
EJD	Ejector door
VN	Ventral nozzle
2-DN	2-D nozzle
HOVER	Hover mode
RCS	Reaction control system



EJECTOR AUGMENTOR



REMOTE AUGMENTED LIFT SYSTEM

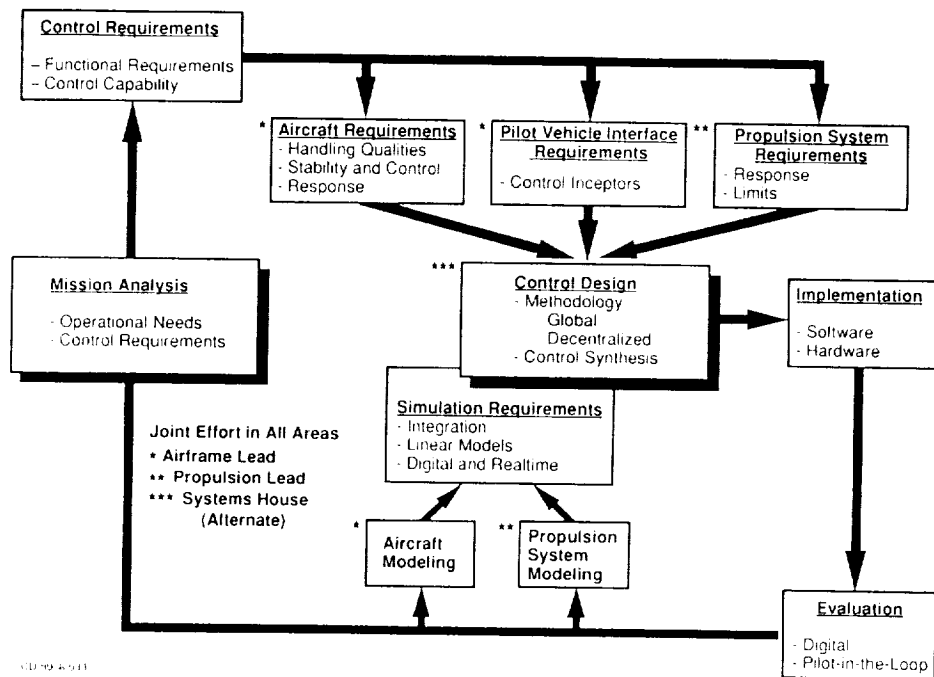


MIXED FLOW VECTORED THRUST



HYBRID TANDEM FAN

Fig. 1 US ASTOVL aircraft configurations.



ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Fig. 2 Integrated flight-propulsion control design process.

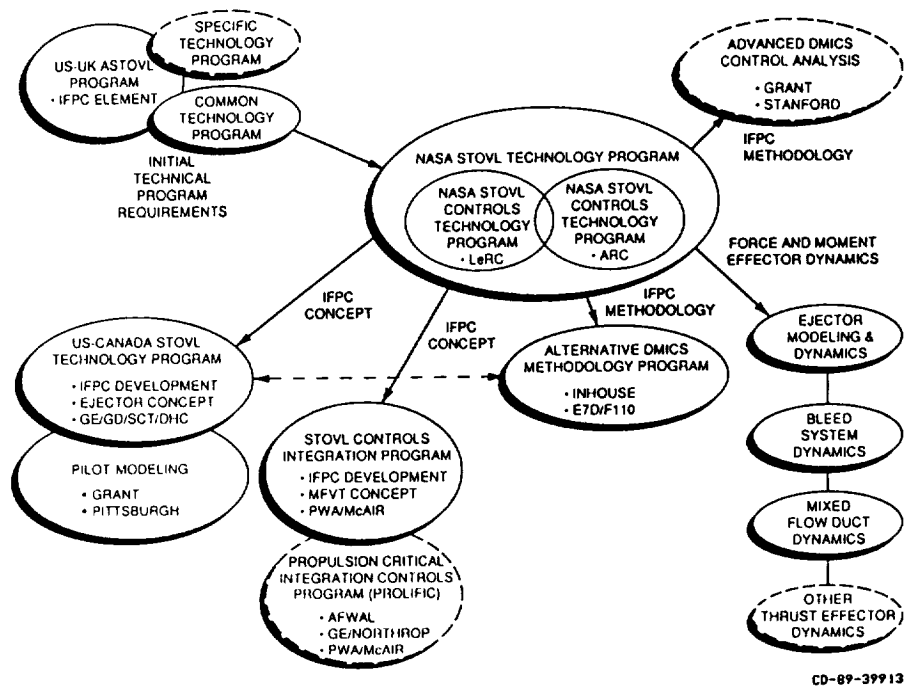


Fig. 3 STOVL integrated flight propulsion controls research.

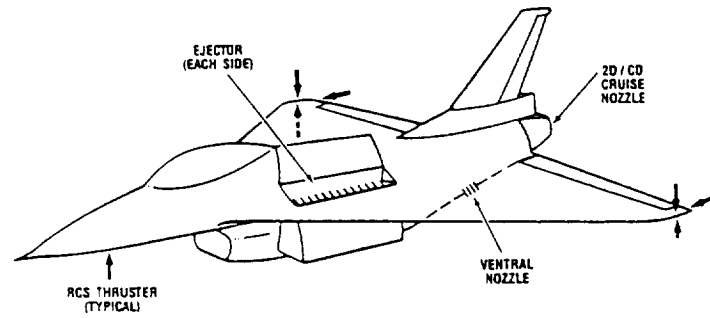


Fig. 6 E-7D/Ejector configured aircraft.

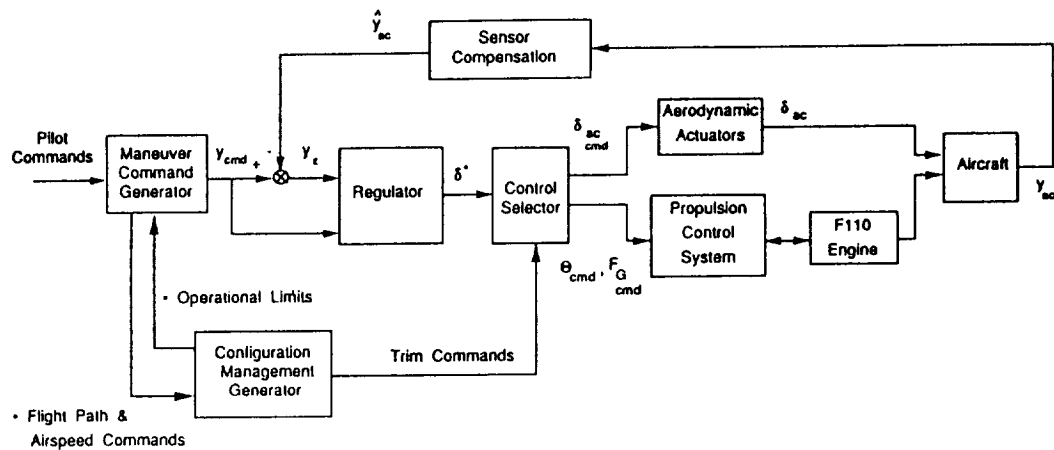


Fig. 7 General IFPC block diagram.

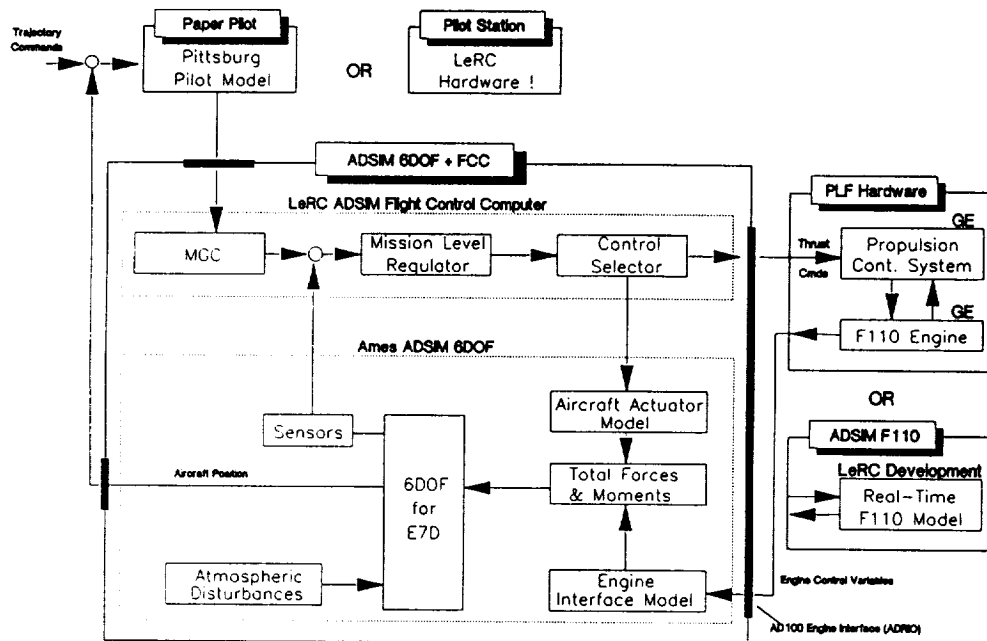


Fig. 8 Overview of E-7D simulation structure and options.

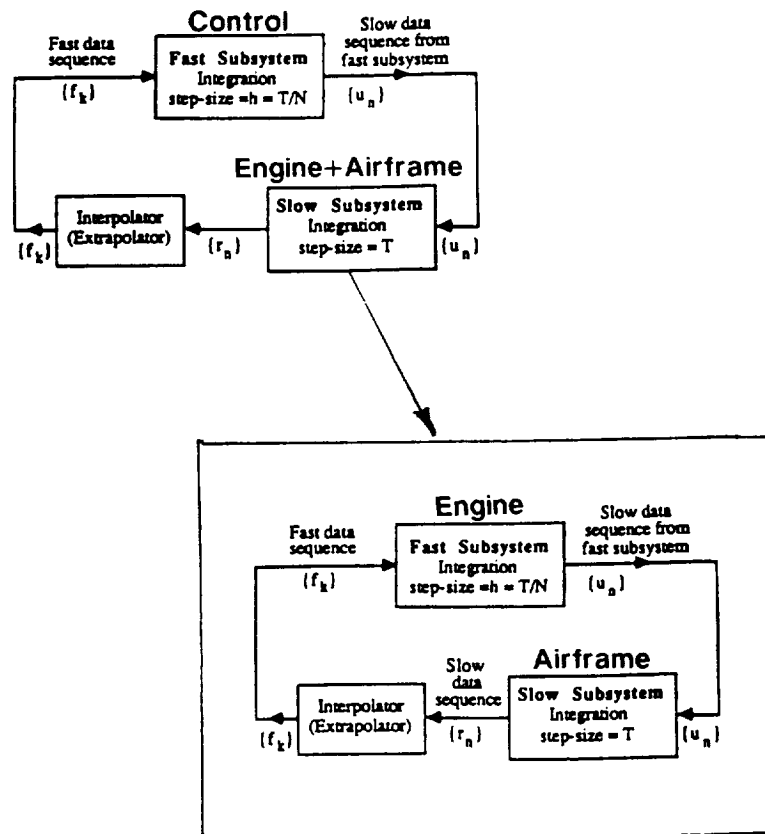


Fig. 9 Multi-frame aspect of the E-7D simulation.

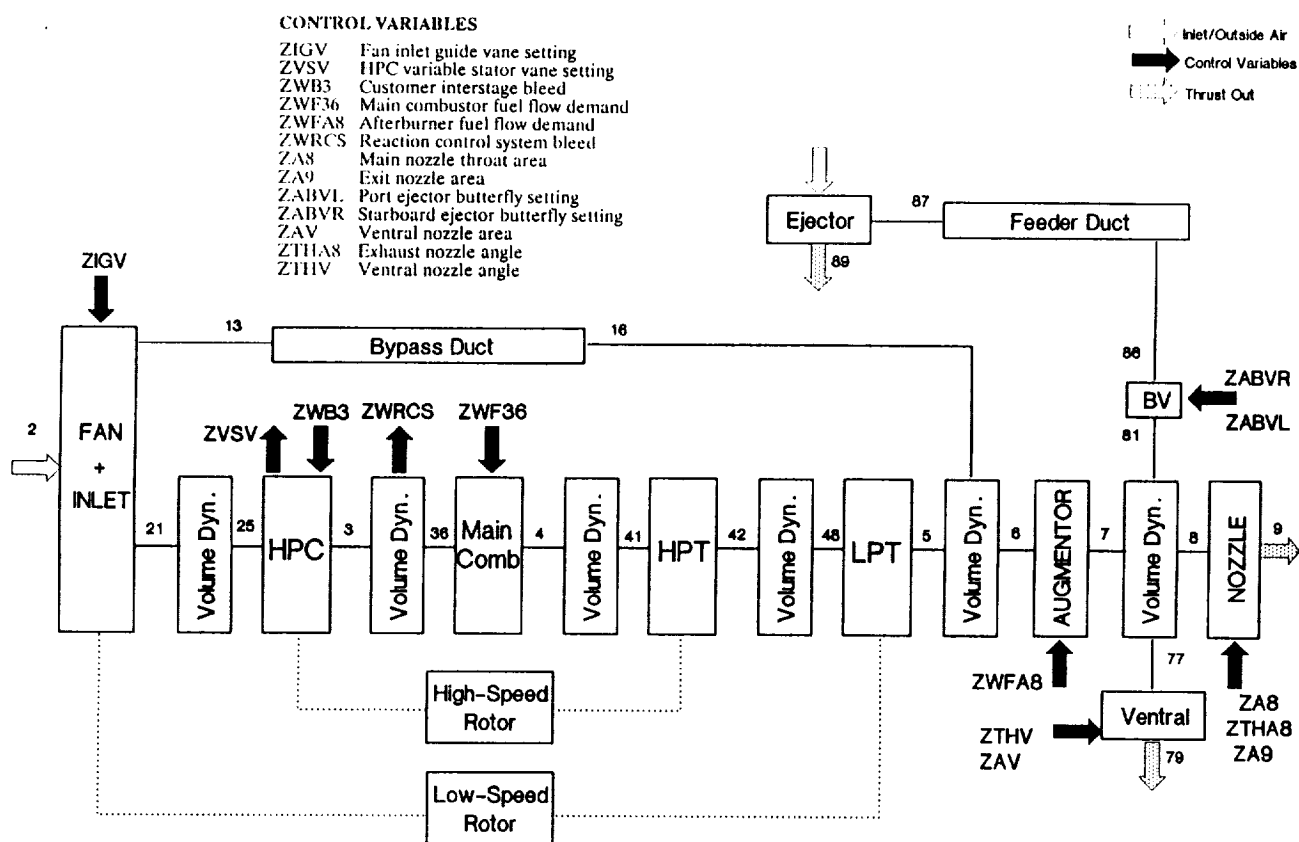
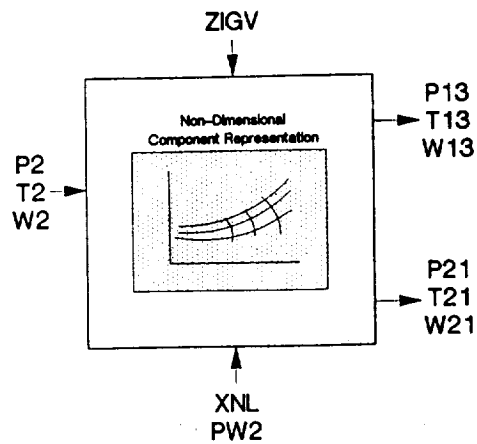
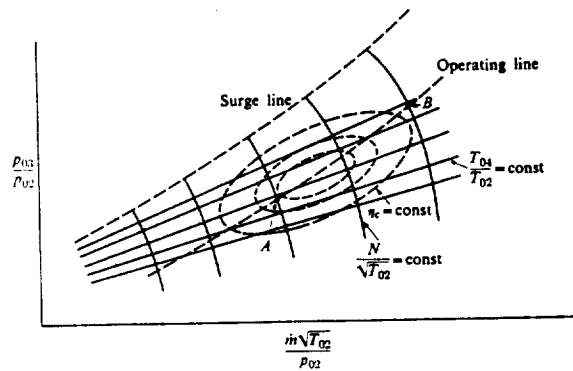


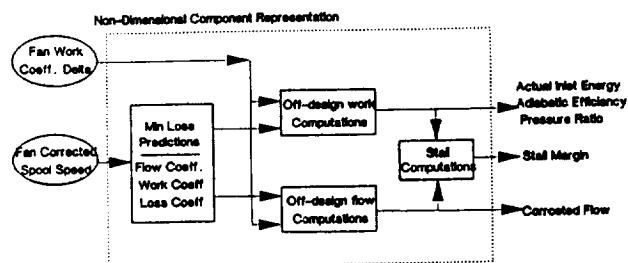
Fig. 10 Component level propulsion system model.



a) Generic fan block



b) Conventional compressor map



c) "Backbone" map

Fig. 11 Fan block approximations.

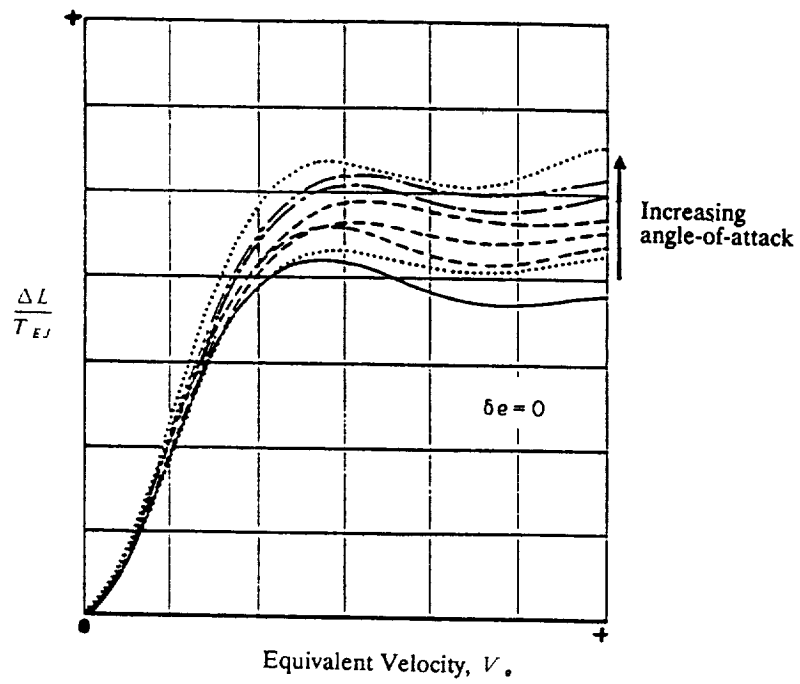


Fig. 12 Ejector induced aerodynamic increment.

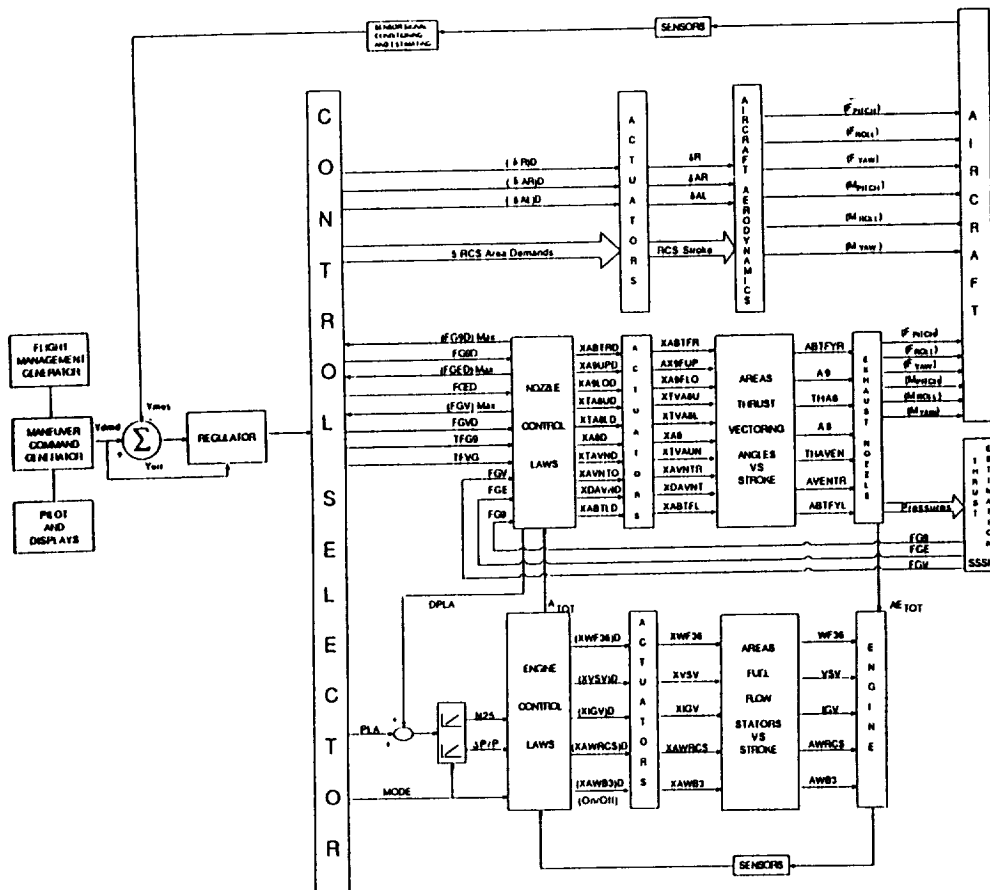


Fig. 13 IFPC block diagram (using thrust sensor feedback).

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16. Abstract <p>The United States is in the initial stages of committing to a national program to develop a supersonic short takeoff and vertical landing (STOVL) aircraft. The goal of the propulsion community in this effort is to have the enabling propulsion technologies for this type aircraft in place to permit a low risk decision regarding the initiation of a research STOVL supersonic attack/fighter aircraft in the late mid-90's. This technology will effectively integrate, enhance, and extend the supersonic cruise, STOVL, and fighter/attack programs to enable U.S. industry to develop a revolutionary supersonic short takeoff and vertical landing fighter/attack aircraft in the post-ATF period. A joint NASA Lewis and NASA Ames research program, with the objective of developing and validating technology for integrated-flight propulsion control design methodologies for short takeoff and vertical landing (STOVL) aircraft, has been planned and is underway. This program, the NASA Supersonic STOVL Integrated Flight-Propulsion Controls Program, is a major element of the overall NASA-Lewis Supersonic STOVL Propulsion Technology Program. It uses an integrated approach to develop an integrated program to achieve integrated flight-propulsion control technology. Essential elements of the integrated controls research program are realtime simulations of the integrated aircraft and propulsion systems which will be used in integrated control concept development and evaluations. This paper describes pertinent parts of the research program leading up to the related realtime simulation development and remarks on the simulation structure to accommodate propulsion system hardware "drop-in" for "real" system evaluation.</p>					
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